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51st Internationales Wissenschaftliches Kolloquium
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Influence of a parameters of high-speed induction heating and properties of materials on thermal and thermostress state of blanks

Electro-Processing Technologies

1. Introduction

In the given work the high-speed modes of through induction heating [1, 2], thermal and thermostress state of blanks of round and rectangular section are calculated and investigated with use of the developed software package in view of influence of parameters of an electromagnetic field and properties of materials. The generalized dependences of high-speed induction heating of blanks and parts on the basis of researched modes are determined.
The process of high-speed induction through heating of metal blanks of the titan, austenitic steel and other similar materials is offered to carry out by the developed method in some stages for increase of productivity of induction heating installations in view of thermal stresses in heated products. The number of stages depends on a mode of heating, properties of a material and the form of section of blanks.
The speeds of heating, thermal and of blanks choose so that the current meanings of temperature differences and thermostresses at each stage did not exceed permissible values.
The maximal speed of heating of blanks is reached at optimum selection of a mode by the offered method in view of restrictions on thermal stresses.

2. Definition of the problem

The general time of heating of blanks is increased and the productivity of installations of induction heating is reduced at usual heating of products and blanks under processing by pressure with low velocities of heating and with maintenance of required uniformity of heating.

The rate heating - heating with the large specific superficial powers applies for increase of productivity of installations of induction through heating (in particular, under processing the pressure). However thus there are significant temperature differences and large thermal stresses in heated products and blanks which can exceed permissible values at given temperature and to result in a marriage. The similar problems arise at induction superficial hardening of parts.

The method of calculation of regimes of high-speed rate induction heating of blanks in some stages is offered by authors [1-4]. The specified method takes into account the generalized dependences.

With use of the developed software package the tasks on research and calculation of regimes of rate induction heating of products are solved in view of influence of parameters of an electromagnetic field and thermal and mechanical properties of various materials on thermal and thermostress state of blanks.

3. Results of investigations

There were conducted investigations of effect of current frequency (depth of electromagnetic wave penetration) on the distributions of temperature, temperature stresses and deformations in the cylindrical blank under high-speed induction heating at the first stage with example of blank in austenite steel by diameter 60 mm at the constant specific surface power p_{0I} = 500 kW/m^2 on the frequencies of current 2400 Hz, 440 kHz and 1760 kHz at the instant of time τ_I = 10 s. The frequencies 440 kHz and 1760 kHz are taken for an illustration and imitation of superficial heating in the calculated analysis. The results of these studies are given in Fig. 1. Obtained distributions of temperatures (Fig. 1,*a*), temperature stresses (Fig. 1,*b*) and deformations (Fig. 1,*c*) correspond to the following curves: *1* – 1760 kHz, *2* – 440 kHz, *3* – 2400 Hz. From the analysis of results it is follows that when the frequency of current raise from 2400 Hz to 1760 kHz the temperature difference over the blank section increases from 130 to 230 °C and the temperature stresses and deformations come nearer the yield strength (curve 4 in Fig. 1,*b*) and in some cases may exceed it and as a result, the defects in material are possible.

The values of heat-conductivity coefficients in metals λ are between the wide limits of 5 and 430 W/(m·K). The heat-conductivity – temperature relationships are very various: as the temperature goes up, the coefficient λ of some metals and alloys is decreased, of others – remains almost unchanged and in some metals and alloys it grows.

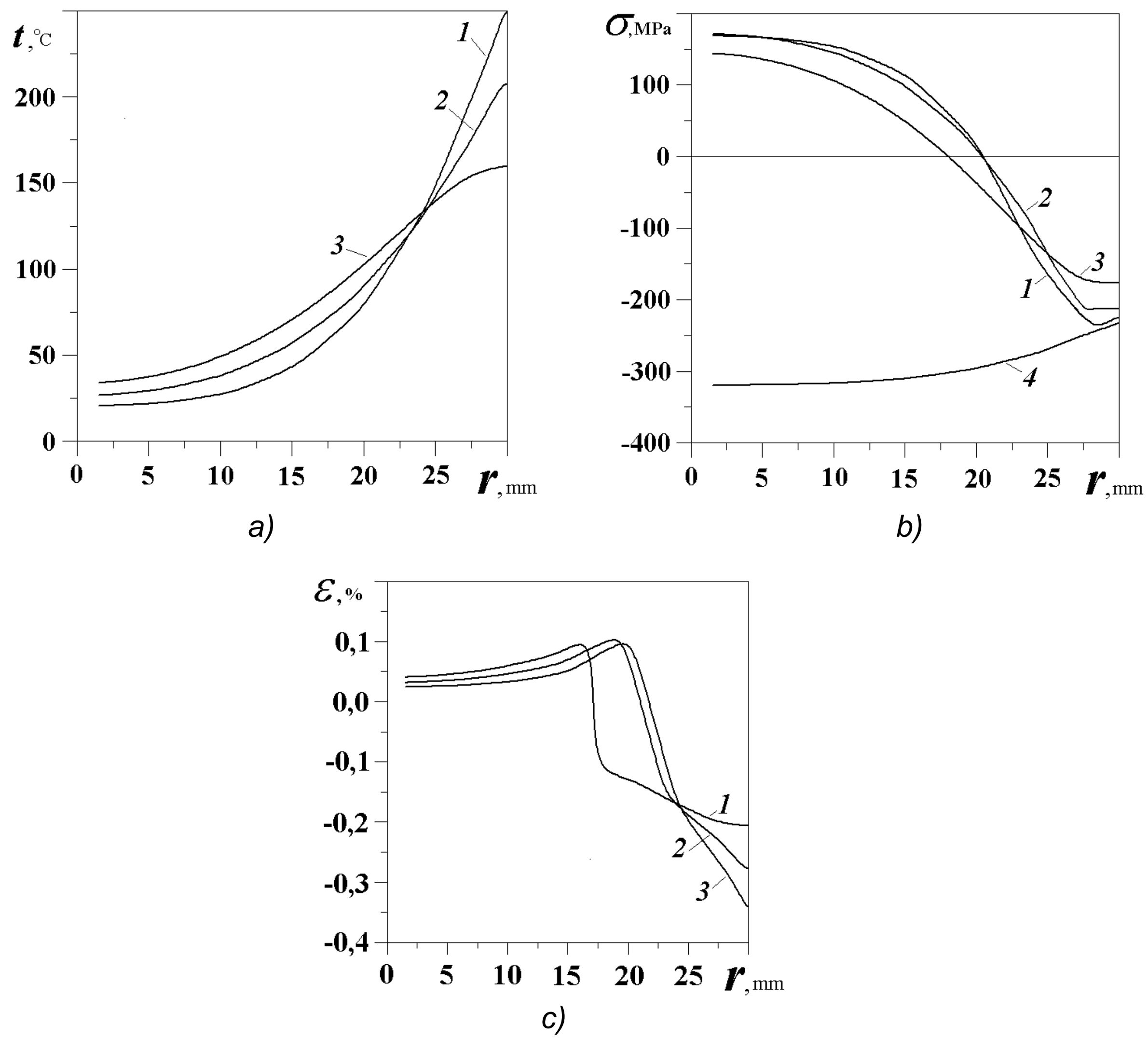

Fig. 1. Distributions of temperatures (*a*), thermal stresses (*b*) and deformations (*c*) in blank in austenitic steel at frequencies of a current: *1* - 1760 kHz, *2* - 440 kHz, *3* - 2400 kHz, *4* - a curve of a limit of fluidity (*b*)

In particular, coefficient λ of titanium alloys, austenitic steels, aluminum and copper alloys is increased with elevation of temperature and λ of ferromagnetic steel is reduced. However, λ of pure copper and aluminum decreases while raising the temperature.

There were studied the modes of high-speed induction through heating of blanks in several characteristic materials: ferromagnetic and austenitic steels, titanium, aluminium and copper alloys with taking account of permissible heating rates and material properties. As a result, we will show the effect of heat-conductivity and strength properties on these modes.

The first stage of high-speed induction heating is characterized by high rates of heating and large thermal stresses. So, on the basis of made calculated investigations at this stage of high-speed heating modes for different steels and alloys there were obtained the curves of permissible heating rates depending on the different diameters of blanks *d* or dimensions of product or blank square-section sides *a* for various materials (Fig. 2): titanium alloys (curve *1*), austenitic steel (curve *2*), titanium alloys with increased strength and others (curve *1′*), ferromagnetic steel (curve *3*), aluminum alloys (curve *4*), copper alloys with λ = 300 W/(m·K) (curve *5′*) and λ = 385 W/m·K – M0, M1, M2 and others (curve *5*). Further the effect of heat-conductivity of material on the temperature differences over the blank section was studied. The specified high-speed modes were determined including the recommended table relationships [3] of frequency of current from product diameter values and with heating up to final temperatures on the surface of products at the first stage for curves of corresponding materials: curves *1* and *2* – 350÷450°C; *1′* – 450÷550°C; *3* – 600÷750°C; curves *4*, *5* and *5′* – 250÷400°C. In so doing, there was placed emphasis on the analysis of temperature differences which have not to exceed the permissible values corresponding to yield strength of material under given temperature. At the beginning of high-speed induction heating the increased values of temperature differences over the blank sections were observed as well.

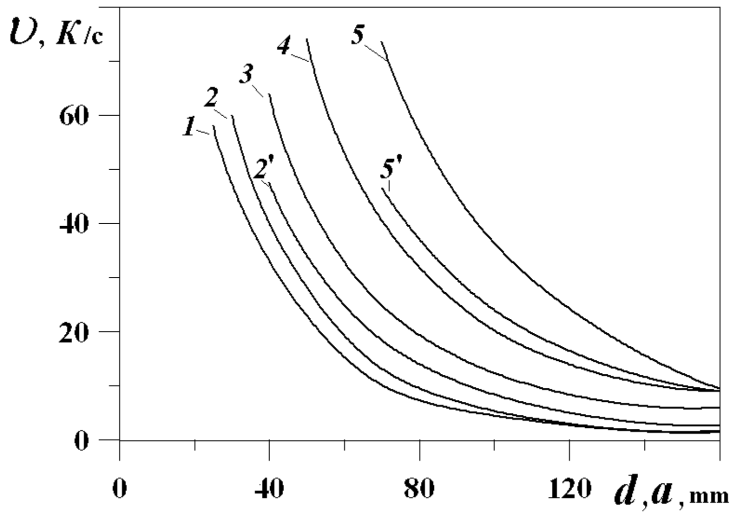

Fig. 2. Curves of permissible heating rates depending on the sizes of products for different materials.

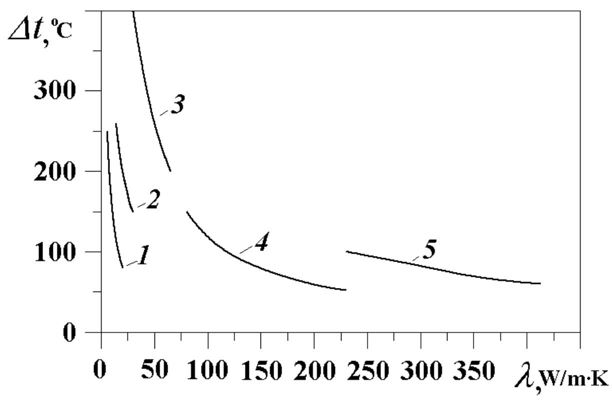

Fig. 3. Dependences of temperature differences on section of cylindrical blanks from heat conductivity of metals and alloys

In Fig. 3 there are presented the results of calculated studies of high-speed induction heating the blanks with diameter of 60 mm in specified steels and alloys (numbering of curves corresponds to Fig. 2) at the medium frequency of current 2400 Hz as an example. From the Fig. 3 in which there are shown the relationships of temperature differences to metal and alloy heat-conductivity it follows that the smaller λ is the larger temperature differences are and vice versa the larger λ is the smaller temperature differences and thermal stresses are. In order of decreasing the temperature differences the materials are arranged as follows: titanium alloys, austenitic steels, ferromagnetic steels, aluminum and copper alloys.

On the basis of data (Fig. 3) it is possible to calculate the differences $\Delta\lambda$ and Δt which characterize the change in heat-conductivity coefficient and temperature differences over the blank sections according to the following ratios: $\Delta\lambda = \lambda_{max} - \lambda_{min}$ and $\Delta t = \Delta t_{max} - \Delta t_{min}$.

By the specified ratios one can to determine $\Delta t/\Delta\lambda$ – the relative change in temperature differences over the blank sections under changing the heat-conductivity coefficient.

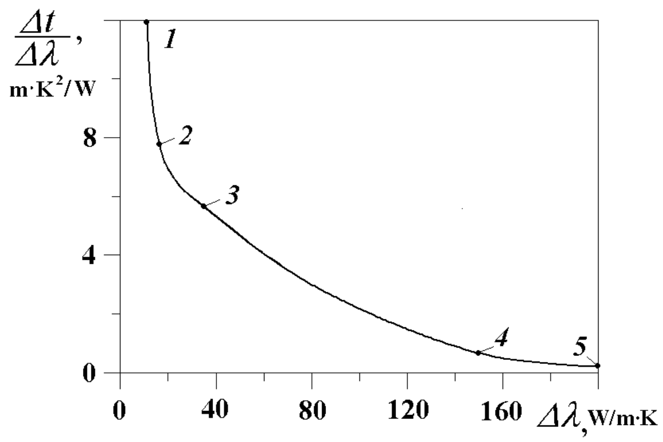

Fig. 4. Curve $\Delta t/\Delta\lambda$ depending on $\Delta\lambda$ for different materials.

In Fig. 4 the general relationship $\Delta t/\Delta\lambda$ as function $\Delta\lambda$ for different materials is shown. It follows from these data that under high-speed induction heating the titanium alloys have the greatest relative change in temperature differences $\Delta t/\Delta\lambda$ = 12 and the copper alloys have the least one $\Delta t/\Delta\lambda$ = 0.22. The relationships given in the Fig. 2, 3 and 4 make it possible to select required parameters of blank heating modes at the initial stage of calculating the modes of high-speed induction heating.

4. Conclusion

The modes of high-speed induction through heating of blanks from several characteristic materials: ferromagnetic and austenitic steel, titanic, aluminum and copper alloys in view of parameters of high-speed induction heating and properties of materials have been investigated. In particular, the influence of characteristics of heat conductivity and strength of materials on the specified modes is investigated. Dependences of allowable speeds of heating from the sizes of blanks and dependences of temperature differences on section blanks from heat conductivity different steels and alloys at the first stage of high-speed induction heating are received. The specified stage is characterized by high speeds of heating and the big thermal stresses. Use of allowable temperature in the beginning of process of heating allows to reduce general time of heating of blanks.

Necessary parameters and modes of high-speed heating of products and blanks can be chosen with the help of the generalized received dependences.

The obtained recommendations and results of investigations can find wide application at development of effective high-speed modes of induction heating of blanks and parts in various branches of mechanical engineering.

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